# TECHNICAL OPINION ON THE RISKS OF CONCURRENT DEVELOPMENT OF OIL AND GAS NEXT TO NEW MEXICO POTASH MINES

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*by*


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# Report of Dr. Leo L. Van Sambeek

I, Dr. Leo L. Van Sambeek, Manager of Mine & Field Services for RESPEC and a registered professional engineer in the states of New Mexico, Kansas, and South Dakota, was asked to help answer the question, "What dangers do oil and gas drilling or wells pose to underground potash mines in New Mexico?" This report presents my qualifications for conducting the work, my analyses, and my findings and conclusions.

## 1.0 QUALIFICATIONS

My education and experience qualify me to answer the above question and my credentials are summarized as follows.

I hold bachelor and master of science degrees in mining engineering from the South Dakota School of Mines and Technology (1972 and 1974, respectively) and a doctorate degree in mining engineering from the Colorado School of Mines (1986). Since 1972, I have worked for the engineering consulting firm, RESPEC, Rapid City, South Dakota. About 30 years of my consulting work have dealt directly with the salt- and potash-mining industries and the underground storage-in-salt industry.

My technical expertise is developing salt-rock mechanics principles and applying those principles to salt- and potash-mining engineering. In that regard, I have written over 80 publicly available reports and papers on various aspects of salt-rock mechanics, pillar design (e.g., Van Sambeek [1996]; Frayne and Van Sambeek [1999]), subsidence over salt and potash mines (e.g., Van Sambeek [1997; 1999; 2000a; 2000b]), and design of seals for mines and boreholes. My consulting work has allowed me to work in the vast majority of the salt and potash mines in North America and several in Europe; therefore, my experience is broad and first-hand. Because of my work experience and the perspective it provides, operators of mines and underground storage facilities routinely ask me to analyze problems they face.

I have performed due-diligence technical audits for three salt and potash mine acquisitions, including New Mexico potash mines. A significant part of a due-diligence audit is identifying and evaluating risks posed by factors unassociated with the mining operations but factors that potentially bear upon the mines' long-term stability and economic viability. Oil and gas wells near potash mines are just such a "factor."

My personal research, both for my Ph.D. dissertation [Van Sambeek, 1986] and for storage of nuclear waste in salt (particularly for the Waste Isolation Pilot Plant (WIPP) facility near

Carlsbad, New Mexico), is documented in my publications (e.g., Van Sambeek [1981; 1985]) and forms the scientific bases for alternative approaches to modeling creep behavior and monitoring damage evolution of salt rocks. My scientific developments have since been applied in a practical sense for the past 15 to 20 years at such critical facilities as the Strategic Petroleum Reserve (e.g., Van Sambeek et al. [1994]), radioactive-waste disposal at WIPP (e.g., Van Sambeek et. al. [1993a]), numerous salt and potash mines, and underground hydrocarbon storage facilities and salt solution mines.

My career includes several unique experiences involving engineering "disasters and problems," some of which I will describe further in this report. Examples include the intentional flooding of the Belle Isle (Louisiana) salt mine; the accidental flooding of the Jefferson Island (Louisiana) salt mine; the Kanapolis (Kansas) salt mine blowout; the Hutchinson (Kansas) natural gas explosions; the Esterhazy (Saskatchewan) potash mine water inflow; the Colonsay (Saskatchewan) potash mine water inflow; water leakage into, the oil recovery from, and subsequent flooding of the Weeks Island (Louisiana) oil storage facility; the Ocnele Mari (Romania) salt mine collapse; the inflow and collapse of the Retsof (New York) salt mine; and the casing corrosion and subsequent water and gas leakage into the Hockley (Texas) salt mine. I have also worked at an even greater number of facilities where there were no "disasters." However, the fact that some facilities exist without disasters has not precluded "disasters and serious problems" at similar facilities.

A copy of my curriculum vitae (résumé) is attached to this report.

## 2.0 SUMMARY AND CONCLUSIONS

The dangers I anticipate if oil and gas development occurs in close proximity to potash mining are of two types:

- Oil and gas wells can be a pathway for the migration of hydrocarbons or water along poorly cemented boreholes. The direction of flow could be either up or down relative to the potash mines. Around the New Mexico potash mines, gas migration is more of a concern than water migration, except for the possibility of encountering pressurized water in the Castille Formation.
- Oil and gas wells could be a source of leakage for hydrocarbons from simultaneously damaged production- and salt-protection casings. Damage could occur during the production of gas or later after abandonment of gas or oil wells.

Five examples of incidents are described in this report. I selected the incidents to illustrate:

1. The explosive effect of methane gas in a mine; specifically, a rock salt mine where five miners died.
2. The consequences of a gas leak into a mine where 18 members of an inadequately prepared work force were killed because they did not properly deal with a gas leak–a situation that resembles what could happen in a potash mine that is normally nongassy but is subjected to an accidental gas leak from an oil and gas well.
3. That gas can rapidly migrate long distances through rock even at low driving pressures. In this case, natural gas migrated 7 miles through dolomite rock from a Kansas storage cavern to the city of Hutchinson before coming to surface and causing two explosions, which killed two people and disrupted an entire city for weeks.
4. That gas can migrate through salt rock if the salt is damaged by shear stresses. In this case, gas from a storage cavern leaked through 400 feet of rock salt into a brine cavern. Fortunately, the gas was detected and contained before an explosion occurred.
5. The unpredictable results of hydrofracturing (a common oil and gas development practice) and how a planned 50-foot hydrofrac actually ran wild for over 2,000 feet and intercepted a salt mine shaft.

In the final three incidents noted above, the prevailing engineering and scientific opinions before the incident would have been that it was impossible for what actually happened to happen. In these incidents, rock is involved, and rock is not a perfect material. Unintended and unanticipated consequences sometimes occur where rock is used as a protective barrier.

Yates Petroleum argues in their appeal that these dangers do not exist and uses the report of Hazlett and Teufel [2000] as proof. The Hazlett and Teufel report is summarized in their seven conclusions. I repeat each of their conclusions in this section together with my specific opinion about each conclusion and, when appropriate, I provide reference to the section of this report where I discuss my opinion's foundation.

**Hazlett and Teufel's Conclusion 1:** *Gas from a producing, shut in, or plugged and abandoned Delaware oil well will not migrate through the McNutt from the well to a potash mine. Therefore, there is no danger to the miners from having these wells in close proximity.*

Conclusion 1 is based on arguments that the gas pressure, after a limited period of production in the Delaware in combination with the gas-lift process, is insufficient to cause a gas pressure great enough at the elevation of the McNutt to overcome the potash ore's impermeability, pore pressure, and two-phase flow threshold pressure. In my opinion, they fail to recognize that Delaware gas pressure is recoverable given enough time either by gas movement within the Delaware or by time-dependent porosity change. Further, the potash ore in the mine will be subject to damage by dilation and will lose its impermeability and suffer a loss of pore pressure.

**Hazlett and Teufel's Conclusion 2:** *A 60-foot subsidence pillar provides the necessary support to keep the casing surrounded by competent, impermeable rock.*

Conclusion 2 is based on calculated stresses that, in my opinion, are wrong because of an inadequate numerical model and a misinterpretation of the type of damage an oil and gas well casing can suffer from extensional and shear strains. These problems are discussed in Sections 4.1.2.1 and 4.1.2.3.

**Hazlett and Teufel's Conclusion 3:** *Potash mines and Delaware oil wells can exist in close proximity without endangering the lives of the miners due to physics of the relationship between the Delaware Formation and the Salado Formation.*

Conclusion 3 is virtually a restatement of Conclusion 1 and is, therefore, invalid for the same reasons as stated above.

**Hazlett and Teufel's Conclusion 4:** *The natural impediments to fracturing and fluid flow when combined with the man made protections such as casing and cement are additive and provide even a greater level of safety than either system alone.*

While Conclusion 4 is a true statement, any combination of natural impediments and man-made impediments is unquestionably better than either by itself, but the combination does not automatically make a fail-safe system. The combined system has to be assessed based on its weakest link.

**Hazlett and Teufel's Conclusion 5:** *In the past, low pressure Delaware oil wells and high pressure deep gas wells that were drilled out in front of active mine workings were left in subsidence pillars by mining companies as the mines passed by.*

Just because a practice has not caused problems in the past under one set of circumstances does not guarantee the avoidance of problems under a different set of circumstances. Potash-mining methods, mining layouts, extraction ratios, ore types and thicknesses, depths, etc. are changing and evolving as new areas of the basin are mined. Similarly, the methods of well drilling, casing and cementing, developing, and producing are changing also. Taken together, the claimed record of past success might be comforting but is certainly not an absolute indicator of future success.

**Hazlett and Teufel's Conclusion 6:** *Pillar sizes that have been used to isolate wellbores from mining activities in the past have been shown to provide a safe buffer between oil wells and the miners.*

Conclusion 6 seems to be similar to Conclusion 5 but with a closer focus on the pillar as isolating the wellbore from the mine. In fact, we do not know if the pillar has been shown to be a safe buffer because no example is given where we know the wellbore leaked and the pillar was the sole buffer between the wellbore and the mine. Hazlett and Teufel all but ignore the effects of shear stress-induced damage in the potash pillars--see Section 4.2.

**Hazlett and Teufel's Conclusion 7**: *Delaware oil wells drilled out in front of active mine workings in the future can be left in subsidence pillars as the mines pass by without endangering the lives of the miners.*

Conclusion 7 is a build-up conclusion from Conclusions 5 and 6. Because these two conclusions are unacceptable, so is Conclusion 7.

Because of safety issues raised by concurrent development of oil and gas resources in close proximity to underground potash mines, the prudent solution is to separate the two activities, either in time or in space. My conclusion is that underground workers in New Mexico potash mines are subject to an unacceptable risk of gas leaks and possible explosions whenever active or plugged oil and gas wells are nearby, and this situation should be avoided whenever possible. My bases for this conclusion are:

1. Though technically feasible, oil and gas development and production in close proximity to conventional potash mines result in increased risk to the safety of underground workers.
2. Because of both the confined space involved and the limited means of egress from an underground potash mine, workers are particularly susceptible to harm from accidental oil and gas leaks into their mine.
3. No practicable engineering measures are available to eliminate the possibility of a leak from an oil and gas well into a nearby potash mine. Scientific theories of absolute isolation have been shown to sometimes fail in the real world.
4. Reducing the risk to underground workers to an acceptable degree is best accomplished by physically separating the two activities if they are concurrent or delaying the oil and gas development until after the potash mines are closed.

My conclusion is also consistent with the positions taken by regulatory agencies that have considered the issue, as explain in Section 5.

## 3.0 INCIDENTS DEMONSTRATING THE DANGERS THAT OIL AND GAS WELLS POSE TO UNDERGROUND POTASH MINES

Five incidents are described in the following sections to demonstrate the dangers that oil and gas wells pose to underground potash mines. The examples include two incidents where methane explosions occurred in salt-rock mines and caused fatalities and injuries. Two examples illustrate how rock is not always a barrier to gas flow. In one example, dolomite rock allowed stored natural gas to travel 7 miles before exiting the rock and entering a city. In the other example, natural gas migrated through 400 feet of supposedly impermeable salt. Finally, I describe an incident where a common oil and gas development practice behaved much differently than intended or even believed possible.

## 3.1 INCIDENTS OF GAS EXPLOSIONS IN SALT-ROCK MINES

Introduction of gases into any underground mines is always a concern. New Mexico potash mines are considered nongassy; nonetheless, these mines are continuously monitored for methane and spot-checked for other gases (e.g., carbon monoxide, carbon dioxide, hydrogen sulfide). Mining regulations require that each mine's ventilation system operate at an air volume rate capable of diluting to safe levels the expected infiltrations of gases from the rocks and combustion by-products from machinery.

Despite the required gas monitoring and protective measures available, contamination of the mine air by accidental releases from oil and gas wells can cause the concentration of the contaminant to be locally explosive or even toxic. Numerous instances of explosions in mines can be found in the literature. Most of the problems are in coal mines, but two instances are described below where the gas problem was in evaporite (salt rock) mines. Gas entering a salt or potash mine poses a greater danger than when gas enters a coal mine because the gas is unexpected and the mine staff is not as prepared for a quick and decisive response. Consequently, even small amounts of gas entering a New Mexico potash mine can have serious consequences, including life-threatening explosions.

Based on my experience as a mining consultant, Mine Safety and Health Administration (MSHA) would reclassify a New Mexico potash mine as "gassy" if a significant release of gas were to occur from an oil or gas well into the mine. Reclassification to "gassy" would require either a totally new fleet of machinery or substantial modification of existing equipment in order to pass "permissibility" tests in explosive atmospheres. Further, based on my experience, New Mexico potash mines could not justify such a capital expenditure to meet "gassy" mine requirements–the affected mine(s) would likely be closed or need to be converted to another mining method.

### 3.1.1 <u>Belle Isle, Louisiana</u>

In June 1979, an outburst of gas occurred in Cargill's Belle Isle salt mine near Franklin, Louisiana. About 10 minutes after the outburst, an explosion occurred and five underground workers died from the effects of the blast. The gas outburst was methane trapped in the salt and liberated by mining. The 10-minute delay between the outburst and the explosion was because the methane first had to be diluted to an explosive level and then migrate to an ignition source. The miners died from the consequences of a crushing "air blast" and carbon monoxide asphyxiation. Survivors reported hurricane-like winds, and these winds literally threw men and equipment around in the mine.

Although this incident does not involve leakage from an oil and gas well, it does illustrate the type of explosive forces and air quality issues that can occur if hydrocarbon gas leaks from an oil and gas well into a potash mine.

### 3.1.2 Cane Creek, Utah

A gas explosion occurred in Texas Gulf Sulfur Company's Cane Creek potash mine near Moab, Utah, in August 1963. Twenty-five miners were underground at the time, and 18 men died from the flames, air-blast forces, or asphyxiation. Bureau of Mines investigators believe the explosion originated in the area where an explosive mixture of combustible gases was ignited by electrical arcs, sparks, open flame, or heated metal surfaces. Forces of the explosion extended to the shaft station, up the shaft, to the surface. The mine was in the development stage and production of ore had not yet started. Harrison International, Inc. was the contractor sinking the shaft and driving development drifts to the ore body. Practically all work being done at the time of the explosion was by the contractor.

Methane emissions from the drift faces had been noted and measured for some days before the explosion. In fact, methane bleeder holes were being drilled to remove the methane. The seriousness of the methane emission apparently was not recognized by the contractor's employees as several lapses in safety and precautions were discovered by the investigating team. Notwithstanding the inexperience of the contractor employees, a similar situation of "inattentiveness or unawareness of how to handle methane" could happen in a normally nongassy New Mexico potash mine if a gas leak were to occur. The consequences of a gas leak could be similar to those at Cane Creek.

## 3.2 INCIDENTS OF GAS RELEASES FROM STORAGE

### 3.2.1 Hutchinson, Kansas (Natural Gas Storage)

LPG storage wells were drilled to depths of about 650 to 900 feet, into the lower parts of the Permian Hutchinson Salt Member of the Wellington Formation, some 7 miles west-northwest of Hutchinson, Kansas. The LPG storage wells were plugged because of bankruptcy, but later, these wells were reopened for natural gas storage. During January 2001, as a result of a casing breach, gas stored at a pressure of about 600 psi leaked out of one of the storage wells (Well S1).

From the breach in the steel casing, the gas moved vertically up to a laterally continuous fracture zone where it made its way to the city of Hutchinson, entered old brine wells drilled into the salt during the late-1800s, and vented to the surface through those wells that were open and cased only through the shallow near-surface aquifer. The deeper parts of these old wells were open-hole and the gas entered the borehole from the fractured rock and vented to the surface. Two explosions resulted, killing two people, destroying several businesses, and disrupting the city for months.

Perhaps the most important fact, from a risk assessment standpoint, is that the Hutchinson-incident gas traveled some 7 miles at depth and through the rock. Before this incident, few, if any, of the gas-storage industry's geologists, rock mechanics specialists, or storage engineers, would have believed that gas could move 7 miles under such low pressure; yet, that is exactly what happened. A gas-driving pressure of 600 psi is similar to what can exist in a New Mexico gas and oil well (see Hazlett and Teufel, Page 25–26). Henceforth, I must reject any claim that a "certain" thickness of rock between a source of gas and the environment is a guarantee of absolute safety.

I am intimately familiar with the details of this incident because I was in Hutchinson soon after the two explosions and was hired by the city of Hutchinson to advise the emergency response team on how to avoid additional explosions and to determine ways to mitigate the release of natural gas.

### 3.2.2 Spindletop, Texas (Natural Gas Storage)

A connection between a gas storage cavern and a brine cavern in December 2001 in the Spindletop salt dome in Texas is a significant, but unanticipated, geomechanical development in gas storage in salt caverns. The first indication of a problem was abnormally high wellhead pressure in one of the brine supply caverns operated by Texas Brine Company, LLC. This brine cavern is offset from a gas storage cavern operated by Centana Intrastate Pipeline, LLC–a subsidiary of Duke Energy Field Services, LP. The cause for the elevated wellhead pressure was natural gas infiltrating into the brine cavern. Normal wellhead operating pressure on the brine cavern is about 500 psi and the wellhead operating pressure of the gas-storage well at the time of the event was about 3,000 psi. Movement of gas from the gas-storage cavern to the brine cavern was confirmed using pressure and injection tests. During the pressure/injection tests, gas migrated even at storage-cavern pressures less than 3,000 psi. Drilling and sonar measurements confirmed several hundred feet of salt separating the caverns; the usual cited distance is about 400 feet of salt separating the caverns.

In summary, natural gas stored in one cavern at a pressure of approximately 3,000 psi migrated through approximately 400 feet of salt and entered the pressurized brine cavern. Potential pathways include gas migrating through an induced fracture, a fault plane, or a seam of porous and permeable salt intersecting both caverns. Regardless of the exact nature of the path the gas took, the relevant aspect is that the gas migrated through 400 feet of salt despite the relatively low pressure difference between the adjacent caverns (hydrostatic plus 500 psi wellhead for the brine cavern and 3,000 psi for the gas cavern.) My experience in developing scientific evidence for damage in salt rocks (specifically, shear stress-induced dilation) and my underground observations of such damage in potash mines helps me understand how the gas migrated through the salt. The exact same salt-damage mechanisms would be active in any pillar left to protect an oil or gas well. If the well casing leaks, gas can migrate through the damaged salt (potash pillar) and enter the mine, even though a potash pillar surrounds the well. A protective pillar, if too small, is prone to such damage and gives a false sense of security.

## 3.3 OTHER SALT-ROCK MINE INCIDENTS

### 3.3.1 Lansing, New York (Hydrofracture)

Cargill Salt operates the conventional (underground) Cayuga salt mine near Lansing, New York. During 1958, International Salt Company was operating a solution mine about 4,000 feet from the Cayuga Mine shafts. Normally, the unlined shaft of the Cargill salt mine is not dry, but the amount of leakage was small–a few gallons per minute at most. I am told, however, when International Salt performed a "routine" hydrofracturing operation within the salt to connect two wells only 50 feet apart, the shaft leakage rate suddenly increased. The hydrofracturing was stopped and the leakage rate decreased. A second hydrofracturing operation was started because the two wells had not connected and because it seemed improbable, if not impossible, for the hydrofracturing fluid to have traveled the several thousand feet between the hydrofracture well and the mine shaft. But again the leakage rate increased, indicating that the fracturing fluid was indeed being driven through the salt and intervening rock formations to the mine shafts. Cargill Salt was fortunate here because the inflow to the shaft was small, quickly noticed, and consisted of water.

I describe this incident for two reasons: (1) hydrofracturing is a common operation in most oil and gas well development programs and (2) the case history illustrates how something that is "impossible" still sometimes occurs. Hydrofracturing is not always predictable; this incident proves that the induced fracture can propagate in unintended directions and for extreme distances. Therefore, this incident demonstrates that hydrofracturing can occur through salt rocks and, when combined with its unpredictability, can cause unintended fractures and create new pathways for gas migration into a potash mine.

# 4.0 REACTIONS TO HAZLETT AND TEUFEL REPORT CONCLUSIONS

Hazlett and Teufel [2000] describe two analyses they made to study concurrent development of potash and oil and gas: (1) a literature review concerning gas flow and pressurization in salt-rock formations and reports of leakage from wells intercepted by potash mining and (2) a numerical modeling study of pillars in an underground potash mine.

Of their seven conclusions, four are statements or restatements of the proposition that because 89 wells historically coexisted within New Mexico potash mines without evidence of leaking, then that provides sufficient certainty to conclude no well will ever leak in the future. Such conjecture is dangerous. The potash mines and oil and gas wells are (1) working within a geological system that may or may not be the same even over small distances, (2) using engineering principles that are not universally recognized, and (3) relying on man-made



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systems that can be improperly or imperfectly installed. Hazlett and Teufel can not ensure that no failure will occur.

Geological variations are important because what happens in one location under a particular set of circumstances might not occur the same way at another location because the rock or the loading conditions are different. Similarly, applying engineering principles to geological materials implies we fully understand both the material and the precise mechanisms involved. My experience is that rarely do we know the geological material (rock) as well as we would like, and surprises are frequent when we assume we have enumerated and understood all the mechanisms involved. On the other hand, when engineered barriers (such as well casings and cement) are used, their reliability demands certain standards of care and workmanship–items which are particularly difficult to judge or test at the large depths involved in wells.

Hazlett and Teufel's three remaining conclusions either result from an interpretation of their numerical modeling results or are claimed to be supported by their modeling results. These conclusions, in my opinion, are not warranted because of fundamental problems with the numerical modeling assumptions, procedures, and results interpretation. Each of the issues is discussed in the following subsections together with the Hazlett and Teufel conclusion affected by the issue.

## 4.1 NUMERICAL MODELING STUDY

The numerical modeling study of Hazlett and Teufel is described as a three-dimensional modeling study to determine the stress states in potash pillars under various combinations of production- and subsidence-pillar dimensions. Several inappropriate assumptions and poor judgment in building their numerical model lead to calculated stresses that are unrealistic. Further, interpretation of the results was incomplete or improper results were interpreted. Summary descriptions of these problems in the numerical modeling are given in the next sections.

### 4.1.1 Unspecified Creep Behavior for the Potash

The creep behavior of the potash was modeled; however, insufficient detail is provided in the report to determine whether their assumed constitutive behavior is appropriate. The reason this is mentioned is that my personal experience in performing and supervising numerical modeling studies of salt and potash mines suggests that the vertical stress profiles presented are inconsistent with the pillar geometries described. In essence, their analyses show lower magnitude vertical stresses in the larger subsidence pillars than in the smaller production pillars. My experience is that if smaller pillars (yield pillars) surround a large subsidence pillar (acting like an abutment pillar), the subsidence pillar will take on additional load (vertical stress), rather than shedding load onto the smaller pillars, as Tuefel and Hazlett suggest. This inconsistency with my expectation can not be checked because of the report's lack of modeling and geometry details.

### 4.1.2 Inappropriate Interpretation of Results

#### 4.1.2.1 Strains Versus Stress

Hazlett and Teufel focus their results interpretation on the magnitude of the stress developed in the subsidence pillar (the pillar in which an oil or gas well is assumed to be situated). Such an interpretation is inconsistent with evaluating the most common modes of casing failure. Basically, there is little chance of developing stresses sufficient to crush or collapse the casing from excessive external loading on the casing; yet, that is the only interpretation provided in the report. In my opinion, the most likely modes of casing failure are either tension failure, where the casing is separated by extensional strains, or shear failure, where the casing is torn apart by differential displacements causing shear stresses in excess of the steel's shear strength. Hazlett and Teufel do not show any calculated results for extensional or shear strains nor provide any discussion on these modes of strain-induced casing failure.

#### 4.1.2.2 Debonding at Cement-Salt Interface

At Page 36 of the Hazlett and Teufel report, the authors discuss the potential for damage at the salt and cement/casing interface. The damage will take the form of debonding (I interpret this to mean slippage) between the salt and cement or between the cement and steel. Such debonding will undoubtedly create a potential flow path. The authors' statement that any open void space will "seal" because of creep of the salt fails to recognize the damage at the cement-casing interface, and that damage at that interface is isolated from being sealed by salt creep. Therefore, gas can migrate along the interfaces.

The integrity of the cement is vital to Hazlett and Teufel's arguments for the certainty of protection against leakage. In my experience, cement integrity is not always achieved during placement and integrity can apparently be lost when most needed. For example, the Hutchinson natural gas disaster is a classic case where the cement between the salt and casing was unable to contain the natural gas once it had penetrated through the casing (see Section 3.2.1). In the Hutchinson incident, natural gas traveled through the cement (or along the interface between the cement and steel casing) until it rose above the salt and lower shale and entered an easier pathway through a thin fractured dolomite layer. Neither the salt nor salt creep was able to "seal" the cement and interface as claimed by Hazlett and Teufel. This example shows how theory and reality sometimes diverge and can have catastrophic consequences; in this case, deaths.

Based on my work at the Mosaic Potash Mine at Esterhazy, Saskatchewan, I know of several wells where cementing of the casing has not been tight. In these wells, water leaks from an overlying aquifer along the outside of the casing and into a lower aquifer. In some instances, we have been able to stop the leakage by perforating the casing and squeezing additional cement behind the casing. This problem is not prevalent, but it does happen, proving that inadequate cementing can occur.

#### 4.1.2.3 Stresses in the Pillars From Oversimplified Modeling

The authors seem to confuse themselves by plotting the maximum (compressive) stress profile and then explaining the distribution (profile) in terms of the vertical stress. The maximum compressive stress at the roof of the mine will be horizontal over the rooms and will continue to be horizontal over narrow pillars. The vertical stress can be maximum over large pillars but only if the pillar is of sufficient width-to-height ratio (W:H) that the horizontal stresses are also large (but still less than the vertical).

Within the geometries modeled, one can not have a large, geometrically stiff (great W:H) pillar located amongst smaller, geometrically soft pillars without the vertical stress being attracted to the large pillar. The reason for this is that the vertical stress and the horizontal stresses in the pillars must be balanced between the large and small pillars such that the creep rate is uniform. Otherwise, the "faster" creeping pillar will move away from the load and force the load to be borne by the "slower" creeping pillar. The authors' model, because of lack of element refinement, can not differentiate stiff and soft pillars. Hence, the calculated stresses for the various-sized pillars are unreliable, and the authors' conclusions based on those calculated stresses are inappropriate.

The most elements in any of their numerical models was 20,000 elements. This is an extremely disproportionate number of elements relative to the stress gradients involved in the numerous pillars modeled. For example, their figures illustrate that only one element is used per 40-foot-wide pillar. Even if this single element is a higher-order element, the calculated stresses can not be representative of reality, particularly when creep is involved. Based on my experience with similar types of numerical modeling of mines and pillars in mines, a reasonable number of elements is several hundred thousand, perhaps more than a million, elements. Hazlett and Teufel's small number of elements is the most likely reason their calculated pillar stresses are not as I would expect for a modeled potash mine.

Because the calculated stresses are not realistic, the conclusions reached based on stress magnitudes and stress distributions are not valid.

#### 4.1.2.4 Calculated Subsidence

Hazlett and Teufel quote the calculated subsidence as a singular magnitude (3.7 feet) for an 8-foot-tall, 2,000-foot-wide square mine. This subsidence magnitude is cited without reference to the time at which it occurs. Subsidence over potash mines is time dependent because of creep deformation in the pillars. This leads me to question: "Is the finite-element model based on infinitesimal strain or finite deformation?" If the model is infinitesimal strain, then the cited subsidence amount without a time reference is meaningless because the calculated subsidence continues unabated in the model. If the model is based on finite deformation, then is the quoted subsidence amount when complete closure has occurred in the mine, and if so, what time period after mining is required to achieve such complete closure?

The accuracy of the calculated subsidence is important to the authors' conclusions on bending of the well casings by subsidence. Buckling or separation of well casings is common in wells over salt solution mines (e.g., Van Sambeek and Ratigan [2002]) even though the total amount of subsidence is substantially less and occurs much slower than over New Mexico potash mines. The width of the calculated subsidence area (angle of draw) is much smaller in the Hazlett and Teufel model results than in the measured results from New Mexico potash mines they cite. Hence, in an actual potash mine situation, wells farther from the potash mine will be affected by subsidence more than is portrayed by the modeling results.

## 4.2 ANALYSIS OF HISTORICAL INFORMATION

The Hazlett and Teufel report concludes, "There has never been an incident where oil or gas has escaped a well and flowed into a potash mine." This may well be the current case; however, past success is no guarantee of future behavior. The integrity of wells, absence of geological flaws or anomalies, imprecision of mining, etc. all make predicting the future a probability exercise. When all the factors are considered, the risk of a leak is greatly increased by proximate oil and gas development, and if there is a leak, the chances of an explosion exist and could cause the death of underground miners. The role of prudent regulations is either to minimize the probability of occurrence or to minimize the impact of an occurrence. The role of engineering is to evaluate the risks and determine appropriate measures to protect the health and safety (in this case primarily of the underground miners) while maximizing the recovery of the minerals and oil and gas. Failure to evaluate the risks and apply safeguards could lead to deadly consequences.

Several studies from the WIPP are referenced as proof that fluids can not move through salt rocks, that is that the salt rocks are impermeable. However, I know because of my work at the WIPP, that each of the Sandia studies involved fluid flow measurements made in low-extraction areas (e.g., around a shaft) rather than in pillars in production areas of a high-extraction potash mine. Based on laboratory testing work performed by my company [Van Sambeek et al., 1993b], the "near-impermeability" of salt rocks requires a "no-damage condition [Van Sambeek, et al., 1993c]; whereas, damaged salt rocks have exponentially increasing permeability according to their level of damage. I understand this damage-to-permeability relationship because I participated in the seal-design projects for WIPP where we closely examined gas migration around the seals (e.g., Van Sambeek et al. [1995a]) through the disturbed-salt (damaged salt) zone [Van Sambeek et al., [1995b]. This same disturbed zone will exist in potash pillars;

therefore, the studies cited by Hazlett and Teufel do not support their views and conclusions that gas can not migrate through potash pillars.

## 5.0 COMPARABLE REGULATIONS

I reviewed regulations in comparable situations to better acquaint myself with the precautions states and regulatory groups feel are necessary to provide for the safety of underground miners when oil and gas wells are proposed in proximity to the mines. The Bureau of Land Management (BLM) in the Wyoming trona-mining situation seems to summarize the feeling of the several jurisdictions I checked:

> *"History has shown that mining, and oil and gas operations can behave unpredictably despite the best efforts in the application of newest technology and strict operating practices. Studies, performed under the direction of the JIC, have proven that coincidental development of trona and oil and gas within the MMTA could have catastrophic consequences. This finding is based on the analysis of current drilling and completion standards used in the Green River Basin and the potential for uncontrolled fluid migration from oil and gas wells into the underground mine(s). The safety and well being of underground miners employed in the trona industry is of paramount importance."*
> FEDERAL REGISTER, Vol. 65, No. 13, January 20, 2000, beginning at 65 FR 3243.

Regulations related to potash and trona mining and oil and gas well drilling in Utah, Wyoming, and two Canadian provinces reveal a continuing concern for the risk of hydrocarbon or water migration to the potash mine either through or along the cemented borehole or hydrocarbon leakage from a damaged well. No potash mines yet exist in Manitoba, but the Manitoba Department of Industry, Economic Development, and Mines in October 2005 announced that it will not accept oil and gas rights applications in areas currently under disposition for potash development or potash exploration. The reason stated in their announcement is

> *"Oil and gas operations have the potential to adversely impact the integrity of potash deposits. In order to mitigate this risk, the Department has decided not to dispose of Crown oil and gas rights in the potash disposition area while holders of potash dispositions undertake activities to evaluate potash deposits. The Department hopes the orderly development of the province's subsurface resources will maximize the value of these resources for the future benefit of all Manitobans."*
> INFORMATIONAL NOTICE 05-02, dated October 13, 2005 from Department of Industry, Economic Development and Mines

## 5.1 UTAH POTASH

The Utah Administrative Code dealing with Designated Potash Areas sets certain rules and orders for "drilling, logging, casing, and plugging operations within the salt section to protect against migration of oil, gas, or water into or within any formation or zone containing potash." – (R649-3-28). In addition to the particular rules and orders, notification must be provided to all potash owners and lessees whose interests are within a radius of 2,640 feet (1/2 mile) of a proposed well.

## 5.2 WYOMING (TRONA)

The BLM recognized the potential negative impact of coincidental (concurrent) development of oil and gas reserves on existing trona leases and the need to provide for the continued health and safety of underground trona-mine miners. As summarized in the Federal Register (Vol. 69, No. 134; July 14, 2004), a Joint Industry Committee (JIC), representing trona, and oil and gas industry groups and interests, worked for 4 years addressing issues on the complexities of coincidental development of underground trona and deep oil and gas within the Mechanical Mining Trona Area (MMTA). An MMTA generally defines an area underlain by trona (sodium) deposits of the proper depth, thickness, and quality to support extraction by mining techniques that require an underground workforce. Technical studies and analysis with safety and economic comparisons show that the mineable trona within the MMTA should be completely extracted before development of deep natural gas resources. The JIC agreed on the following approach:

- Expand the MMTA boundary to include a 1-mile lateral safety buffer. This area is to known as the Special Sodium Drilling Area-A (SSDA-A).
- Prohibit drilling of deep natural gas wells until completion of conventional underground trona mining and abandonment of the underground trona mines. Hydrocarbon resources in the MMTA would be conserved for future development.
- Adopt special rules for drilling operations, well completion, production, and abandonment of shallow natural gas wells within the SSDA-A. Shallow gas drilling could be allowed within the SSDA-A on existing oil and gas leases, subject to special rules currently under development.
- Outside of the SSDA-A but within the Known Sodium Leasing Area, allow oil and gas leasing, and drilling of deep natural gas wells utilizing the special rules for drilling operations, well completion, production, and abandonments procedures as adopted by the Wyoming Oil and Gas Conservation Commission (WOGCC) for the entire Special Sodium Drilling Area.

## 5.3 SASKATCHEWAN (POTASH)

Saskatchewan potash mines operate at depths of over 3,000 feet and this underground mining activity has been active for nearly 50 years. Regulations have recognized, since at least 1995, the importance of restricting oil and gas well drilling in the vicinity of producing potash mines (Section 20 Potash Restricted Drilling Areas). My conversation with Saskatchewan's Director of Petroleum Development (Mr. Brian Mathieson, 306-787-2593, November 3, 2005) confirmed continuing restriction of oil and gas well drilling within the designated potash lease area and within an approximate 2-mile-wide buffer area around the perimeter of designated potash lease area for all active potash mines, and that any drilling within the restricted area requires permission of the potash lease holder(s) (i.e., the mining company) and the Saskatchewan Industry and Resources Minister. Requiring the written permission of the mining company ensures that the mining company is informed of the proposed drilling and is provided full opportunity to review in detail the oil-and-gas drilling company's proposed location and depth, and the proposed well's drilling, casing, cementing, and abandonment plans and schedules. While by regulation, the mining company's permission can not be unreasonably withheld, the potash mining companies are provided considerable latitude in order to protect their substantial investment in their mine.

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Ph.D. in Mining Engineering, Colorado School of Mines, Golden, CO (1986)
M.S. in Mining Engineering, South Dakota School of Mines and Technology, Rapid City, SD (1974)
B.S. in Mining Engineering, South Dakota School of Mines and Technology, Rapid City, SD (1972)

**Registration:** Professional Engineer, states of Kansas, New Mexico, and South Dakota

**Primary Technical Areas:**

- Salt and Rock Mechanics for Mining and Underground Storage
- Numerical Modeling and Structural Analysis
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### Qualifications/Experience:

Dr. Van Sambeek has over 30 years' experience in performing rock and salt mechanics-related studies, supporting mine-design efforts, and providing technical expert services to the underground storage and mining industries. His rock mechanics experience includes drilling and instrument installation; in situ test planning, management, and operation; data acquisition and interpretation; laboratory testing; and numerical modeling. Most of his mining experience is from work in salt and potash mines, and his storage experience includes liquid and gas storage in salt caverns. As a technical expert, Dr. Van Sambeek provides technical advice to legal teams, and he has been deposed as an expert in mining engineering, rock and salt mechanics, and surface subsidence.

Dr. Van Sambeek's technical specialty is salt rock mechanics, and he has consulted at most of the North American salt and potash mines and at several European sites. His expertise includes pillar design, ground control, and surface subsidence engineering. For his Ph.D. dissertation, he researched methods for describing salt creep behavior under the nonuniform stress states found in mine pillars and around storage caverns in salt. He has published several papers on the topic of salt and potash pillar design and the link between field observations of pillar behavior and three-dimensional numerical modeling. He authored one of the original computer programs (a predecessor to SALT_SUBSID) used to interpret and predict the creep-driven, but geometrical and mining-sequence controlled, subsidence over salt and potash mines and solution-mined caverns.

Dr. Van Sambeek was the Principal Investigator and Project Manager for the Avery Island (Louisiana) Salt Mine Test Program, a 5-year in situ experiment to gather first-of-its-kind information on domal salt behavior. The program required installation and operation of nearly every type of rock mechanics instrument and the design of several prototype tests to study creep and fluid flow (permeability) in salt. For the next 6 years, he was Project Manager for the installation, operation, and maintenance of geotechnical instruments in Sandia's thermal/structural experiments in the Waste Isolation Pilot Plant (WIPP). After that, he was Project Manager for rock mechanics support to Sandia's WIPP plugging and sealing program, which involved laboratory testing, numerical modeling of sealing concepts, and in situ test design.

Dr. Van Sambeek is past president of the Solution Mining Research Institute (SMRI), an international research consortium of commercial salt mining and storage companies. Because of his experience in the field, he organized a special SMRI symposium on Sinkholes and Unusual Subsidence Related to Salt and Potash Mining. Several case-history papers from this symposium were the first release of proprietary information and data on significant sinkholes and long-term

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subsidence events. He consulted on the Ocnele Mari salt-solution mine collapse (sinkhole) in Romania, including site inspections and surface subsidence interpretation.

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